A CORRELATION ANALYSIS OF EMG ACTIVITY AND THE MOVEMENT OF SELECTED SPEECH ORGANS

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Introduction

In the study of the dynamic aspects of speech production, it is ultimately necessary to investigate the pattern of motor control signals from the central nervous system and the dynamic characteristics of the speech organ(s) which act(s) in response to the control signals. Although the pattern of the motor control signal has usually been observed in the form of electromyographic (EMG) potentials, the quantitative analysis of the relationship between EMG activity and articulatory movement has remained difficult. Cinefluorographic observation combined with simultaneous recording of EMG signals has been considered to be most satisfactory, but the acquisition of necessary information is generally resticted due to the dosage problem.

The introduction of the x-ray microbeam system to speech research (Kiritani, Itoh and Fujimura, 1975) solved the dosage problem to a large extent and, at the same time, proved useful for reducing the time required for data analysis. Figure 1 shows a data collection and analysis system in use at the Research Institute of Logopedics and Phoniatrics, Faculty of Medicine, University of Tokyo.

The present study is an attempt to analyze the dynamic characteristics of the movements of selected speech organs recorded by means of our x-ray microbeam system simultaneously with EMG recordings of the activity of the related articulatory muscles during speech. In the present paper, the preliminary results of an analysis of velar movement will be presented as an example, in reference to the pattern of the EMG activity of the levator palatini muscle. The articulatory movement of the velum is known to be controlled almost solely by the activation and suppression of the levator palatini. Velar movement is relatively independent of the movement of the other articulators and, thus, relationship between the displacement of the velum and the EMG patterns of the levator palatini can be considered to be relatively straightforward.

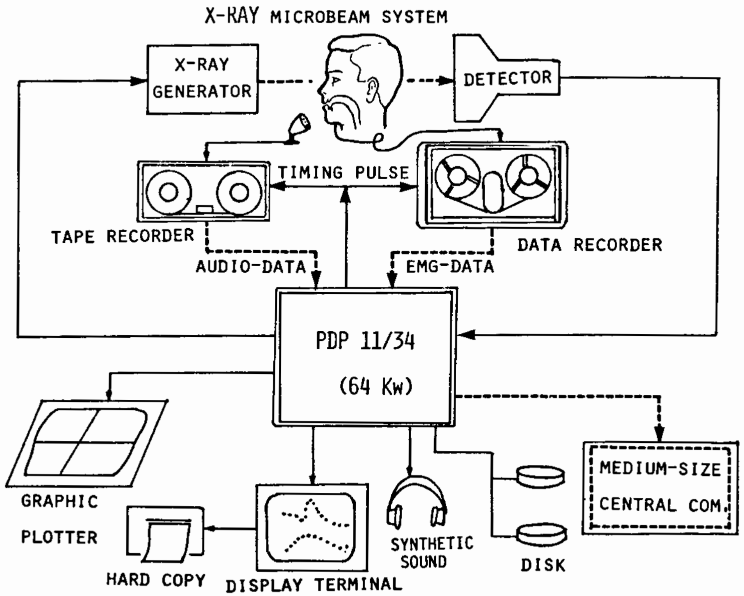

Figure 1 The Articulatory data collection and analysis system at the RILP, University of Tokyo

Data recording

An adult male speaker of the Tokyo dialect served as the subject of the present study. The subject read a list of test words either in isolation or embedded in appropriate frame sentences.

For recording the articulatory movements, the movement of lead pellets attached to the pertinent articulators was tracked and recorded by means of the computer-controlled x-ray microbeam system. For recording velar movement, a strip of thin plastic film with a lead pellet attached to its end was passed through a nostril, placing the pellet on the nasal surface of the velum. The pellet movement was recorded with a frame rate of approximately 190 frames/sec.

Conventional hooked-wire electrodes were inserted into the levator palatini in this particular case. The EMG signals were recorded on an FM data recorder together with the speech signals

and the timing pulses which were generated from the computer for each frame of the x-ray tracking. The EMG signals were then digitized through an A/D converter with a sampling rate of 8 kHz. Absolute values were taken and integrated over 5.83 msec,the value of which corresponds to the interval between successive timing pulses.

Data analysis

The Y-coordinate of the pellet on the velum was selected to represent the movement of the velum, and the relationship between the time function of the coordinate value and the EMG signal was examined. EMG activity is associated with the generation of muscle force and, therefore, can be related to such variables as the displacement, velocity and acceleration of the movement of the pertinent articulator. Thus, the present analysis aimed at obtaining a quantitative estimation of the relationship between these variables and the EMG signal.

It was assumed that the EMG activity of the levator palatini at a given instant could be expressed as the sum of the three components dependent on the displacement (y), velocity ($\dot{y}$) and acceleration ($\ddot{y}$) of the movement of the velum. Thus, an estimated EMG signal at a given time can be given as in equation (1).

$$\hat{E}_i = c_0 + c_1 y_i + c_2 \dot{y}_i + c_3 \ddot{y}_i \quad \text{--- (1)}$$

In this equation, the subscript i denotes the i-th time sample. The above equation indicates that velar movement is realized as the response of a linear second order system to the EMG signal which is given as input. The coefficients which give the best approximation were estimated by the least square error method. That is, for every time sample of EMG signal E_i, the estimate $\hat{E}_i$ in equation (1) was formed by using the coordinate values obtained by x-ray tracking. The coefficients, c_{0-3} were determined by minimizing the value of error (E_{rr}) in equation (2).

$$E_{rr} = \sum_i (E_i - \hat{E}_i)^2 \quad \text{-----(2)}$$

In the above procedure, it was necessary to introduce a temporal smoothing of the observed coordinate value, since, without smoothing, the noise components in the calculated velocity and acceleration were so dominant that virtually no effective correlation could be observed between these variables and the EMG signals. In order to reduce the noise effect, the temporal variation of the coordinate value within a short time window was approximated by the parabolic function of time. In the data sets obtained in the present study, it was found that the error was minimum for a time window of about 30 frames. Thus, in the present analysis, the values calculated for this time window width were considered to be the best estimates of the coefficients.

Results and discussion

The characteristic constants of the linear second order system were calculated from the estimated values of the coefficients in equation (1). The value of the damping factor was found to be close to 1, which implied that the second order system is critically damped. The characteristic time constant was approximately 80 msec, regardless of the difference in speaking rate.

Figure 2 shows examples of the x-ray and EMG data obtained. These curves correspond to the three different types of test words, /bemee/, /beN'ee/ and /beNmee/, each of which was embedded in a frame "sorewa _______desu" (that is _______). In the test words, /N/ represents the syllable final nasal element in Japanese. The sequence of nasal segments /Nm/ is generally uttered as a geminate nasal consonant. For each test word, the curve at the top shows the audio signal, the second and third curves are the temporal patterns of the Y-coordinate value for the lower lip and the velum, respectively. The bottom curve shows the integrated raw EMG, with the estimated EMG curve calculated by using equation (1) superimposed.

It can be seen that in /bemee/ the velum lowering for /m/ starts immediately after the oral release of the initial /b/ and continues until the release of /m/. Velar elevation then begins, the speed of which appears to be slower than that of lowering, and, as a result, the temporal pattern of velar movement is asymmetrical for the production of /m/. In /beN'ee/, the velum lowering for /N/ continues longer, and the velar displacement is larger than for /m/ so that the temporal pattern appears to be symmetrical. In /beNmee/, the level of the maximum velum lowering for /Nm/ is higher than for /N/ in /beN'ee/, although the duration of nasaliza-

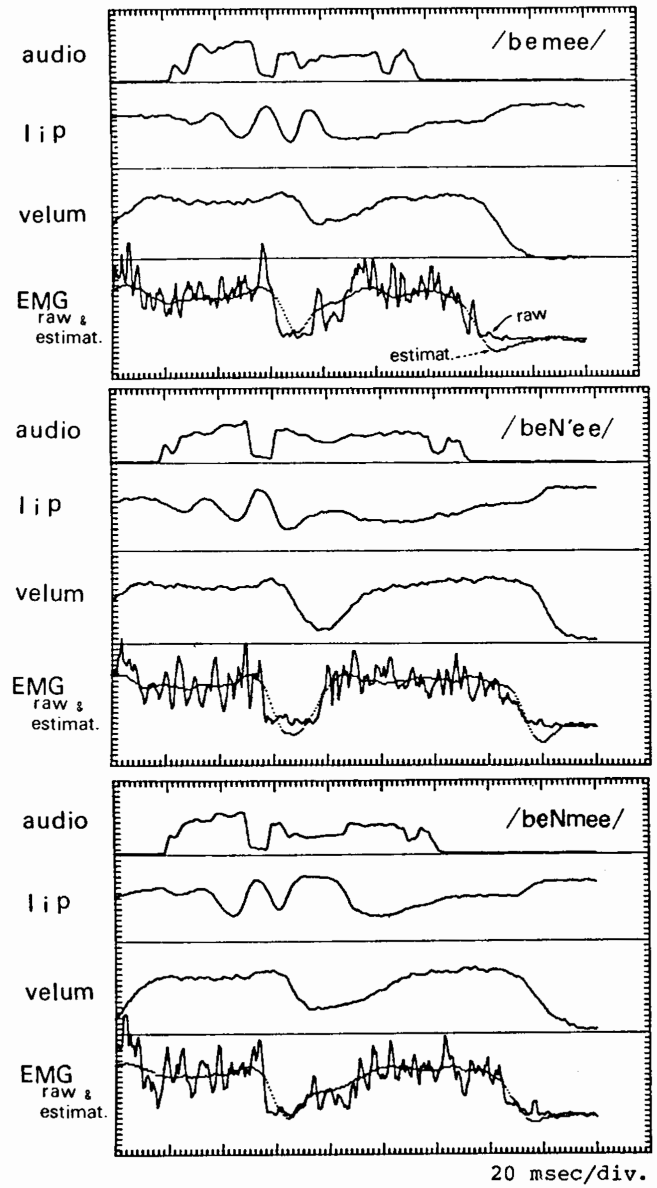

Figure 2 The temporal patterns of the Y-coordinate value for the lower lip and the velum, compared with the audio signal (top) and the raw and the estimated EMG curves (bottom).

tion is longer. In this case, after reaching the level of maximum lowering, the velum appears to stay at, or to ascend very gradually from, that level and, thereafter, it ascends with a speed similar to that for /m/ in /bemee/.

Comparing the patterns of the raw EMG activity with those of the velar movement, it appears that the pattern of levator activity for /N/ in /beN'ee/ is characterized by a step-like EMG suppression, the level of which is the same as that for the resting position of the velum after the cessation of the utterance. In other words, the movement of the velum for /N/ can be regarded as a smoothed response of the velum as a second order system to the step-like control signal to the velum. In /beNmee/, on the other hand, a rapid suppression of levator activity is followed by a short period of an intermediate level of EMG activity. Although the EMG level of the initial part of the suppression for /Nm/ is apparently the same as that for /N/ in /beN'ee/, the velum does not show an extreme lowering but stays at a somewhat higher position. Thus, it appears that the period of intermediate level EMG activity mentioned above is responsible for the characteristic pattern of velum movement for /Nm/. The duration of the suppression of the levator activity for /m/ in /bemee/ is relatively short compared to the estimated value of the time constant of the second order system, and, therefore, the pattern of the velar movement for /m/ can be taken as a ballistic impulse response to the EMG signal. However, as seen in Figure 2, a short re-activation of the levator palatini reaching the intermediate level is observed in some utterance samples of /bemee/. Thus, for /m/, a question still remains as to whether the apparent re-activation of the levator palatini may necessarily result in the gradual ascent of the velum after the initial lowering.

The characteristic pattern of each of the three utterance types is also demonstrated in the estimated EMG curve. In particular, the estimated curve for /Nm/ is characterized by the fact that when the EMG activity increases after the negative peak of suppression, the rate of increase is temporarily depressed before it reaches the maximum level, and, as a result, there is a plateau in the estimated curve. This result would indicate that, as far as the second order linear relationship between the levator EMG and velar movement is concerned, the patterns of the velar movement

for /Nm/ can not be accounted for by a constant increase in the EMG activity after suppression. Rather, it can be assumed that an intermediate stage of EMG control is necessary during the phase of re-activation.

It has been reported that there are characteristic differences in the temporal patterns of velar movements for these three utterance types (Ushijima and Hirose, 1974; Fujimura, Miller and Kiritani, 1976). The result of the present study seems to confirm this result. It also suggests that these differences are based on the different patterns of motor control to the velum.

For a better understanding of the dynamic aspects of speech production, further attempts should be made to accomplish the quantitative analysis of the relationship between EMG signals and articulatory movements. A preliminary analysis of jaw movements in reference to the pattern of the EMG activity of the related muscles is now in progress.

<u>References</u>

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